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Fundamental Units and Terms for Biologically-Effective Radiation

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(Received February 7, 1933)

THE methods of rating sources of radiation for various photochemical, biological, therapeutic and prophylactic purposes are at present generally empirical. Perhaps none of the methods is entirely satisfactory and some of them are quite indefensible from the broader view of physics which commonly has not been adequately considered or understood. Particularly in the cure of disorders and the maintenance of health, practice has demanded some kind of method of appraisal of sources before adequate knowledge of the physics of the subject was available for developing a really scientific procedure.

The chief difficulty in accurately appraising sources of radiation for nearly all the many different biological, therapeutic and prophylactic uses is the lack of complete data pertaining to the effectiveness of energy of various wave-lengths. Among the uncounted results of ordinary radiation are erythema, tan, hyperaemia, cure of rickets, prevention of rickets, killing of germs, production of vitamin D and heating bodily tissue at various depths. Spectral data pertaining to effectiveness[1] are available for some of the results of radiation. For some of the many uses, the most effective spectral range and sometimes the most effective wave-length are approximately known. Spectral data are most complete for the production of erythema, which is a by-product of the exposure of human beings to ultraviolet radiation and is readily measured.

From a broad viewpoint the visual sense is merely one of uncounted utilizers of radiation, but, of course, a very generally important one to human beings. The term *lumen* has been coined to express that which radiation produces, as appraised by the visual sense. The lumens supplied by any specific source of visible radiation is determined by multiplying the spectral distribution of radiation by the spectral "visibility" of radiation for each wave-length throughout the visible spectrum and, of course, defining the magnitude of the lumen by arbitrarily choosing a "unit source."

The same procedure provides a basic scientific method of appraisal of sources of radiation for any physical, photochemical, biological, therapeutic or prophylactic use or effect of radiation. Each effect has its own "spectral curve of effectiveness" and only a few of these are known, even approximately, excepting spectral erythemal effectiveness. By no means is the production of erythema an accurate means of appraising sources for the exposure of living matter. It can be little more than grossly approximate in its appraisals. But erythemal effectiveness is at present important in connection with many uses of ultraviolet radiation. It is a by-product of radiation of wave-lengths known to be biologically effective. It is produced by the radiation near the short-wave

[1] M. Luckiesh, *Artificial Sunlight*, D. Van Nostrand Co., New York, 1930.

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limit of sunlight. It is not produced appreciably, or practically at all, by radiation which passes through ordinary glass. Human skin must be protected from severe erythema in therapeutic practice. Still, the general availability of human skin makes it a practical detector of ultraviolet radiation of known biological effectiveness. For these and other practical reasons erythema is important.

The spectral erythemal curve for average untanned skin is shown in Fig. 1, which is our idea of the mean values of spectral effectiveness, as determined by Hausser and Vahle,[2] Coblentz,[3] and Luckiesh, Holladay and Taylor.[4] The relative numerical values are presented in Table I. The

TABLE I. *Average values of relative erythemal effectiveness of ultraviolet radiation of various wave-lengths of mercury-arc radiation in percent of that at λ2967.*

Wave-length	Percent	Wave-length	Percent
2400	56	2753	7
2446	57	2804	6
2482	57	2857	10
2537	55	2894	25
2576	49	2925	73
2654	25	2967	100
2675	20	3022	55
2700	14	3130	3
(Values taken from plotted curve)			
2450	57	2850	9
2500	57	2900	31
2550	54	2950	98
2600	42	3000	83
2650	26	3050	34
2700	14	3100	11
2750	7	3150	0.7
2800	6	3180	0

wave-lengths are those of radiation for the mercury arc because the determinations were made with this source.

With such a curve fairly well determined it is possible to appraise the output of erythema-producing radiation from any source. In a previous paper[5] we suggested the term *viton* analogous to the lumen and, of course, there would be a specific viton for each specific biological effect.

The erythemal viton, which for simplicity might be termed the E-viton, would be the result of properly weighting the spectral energy through a range from approximately λ1850 to λ3200 for such sources as quartz mercury arcs and bare carbon arcs. Only the range from λ2800 to λ3200 is of practical interest in the cases of sunlight and of sources which aim to supply radiation confined to approximately the same spectral range. Furthermore, the spectral erythemal curve is more stable and better determined in the region of its long-wave maximum than its short wave portion.

UNITS AND TERMINOLOGY

There is an immediate need for erythemal units and terms. A consideration of them is desirable for this specific reason and also as an example of what might well be done for other biological effects as soon as the necessary data are available.

Determination of erythema

This involves many variables, but by standardizing conditions it can be accomplished satisfactorily and with consistent results. There are various degrees from minimum perceptible erythema (MPE) to severe cases which eventually are followed by blistering and severe peeling of the skin. Obviously, a combination colorimeter and reflectometer would be necessary to measure any degree greater than the minimum perceptible. If an adequate series of exposures is made on small adjacent areas of skin, the exposure producing a minimum perceptible erythema (MPE) can be determined with considerable accuracy for the particular conditions. After some experience it is possible to predetermine the range of exposures necessary in most cases. For various obvious reasons untanned skin or skin not ordinarily exposed to sunlight is chosen. Of course, the sensitivity of the skin varies considerably for different persons and areas of the body. Also, skin which has been "burned," but shows no visible evidence after the erythema has disappeared, may have a lowered sensitivity for a long time. Inasmuch as the erythema does not become visible for some time after exposure, it is

[2] K. W. Hausser and W. Vahle, Strahlentherapie **13**, 41 (1922); K. W. Hausser, ibid. **28**, Part 1, 25 (1928).

[3] W. W. Coblentz, R. Stair and J. M. Hogue, *The Spectral Erythemic Reaction of the Untanned Human Skin to Ultraviolet Radiation*, Bur. Standards J. Research **8**, 541 (1932).

[4] M. Luckiesh, L. L. Holladay and A. H. Taylor, *Reaction of Untanned Skin to Ultraviolet Radiation*, J. Opt. Soc. Am. **20**, 423 (1930).

[5] M. Luckiesh and L. L. Holladay, *Nomenclature and Standards for Biologically Effective Radiation*, J. Opt. Soc. Am. **21**, 420 (1931).

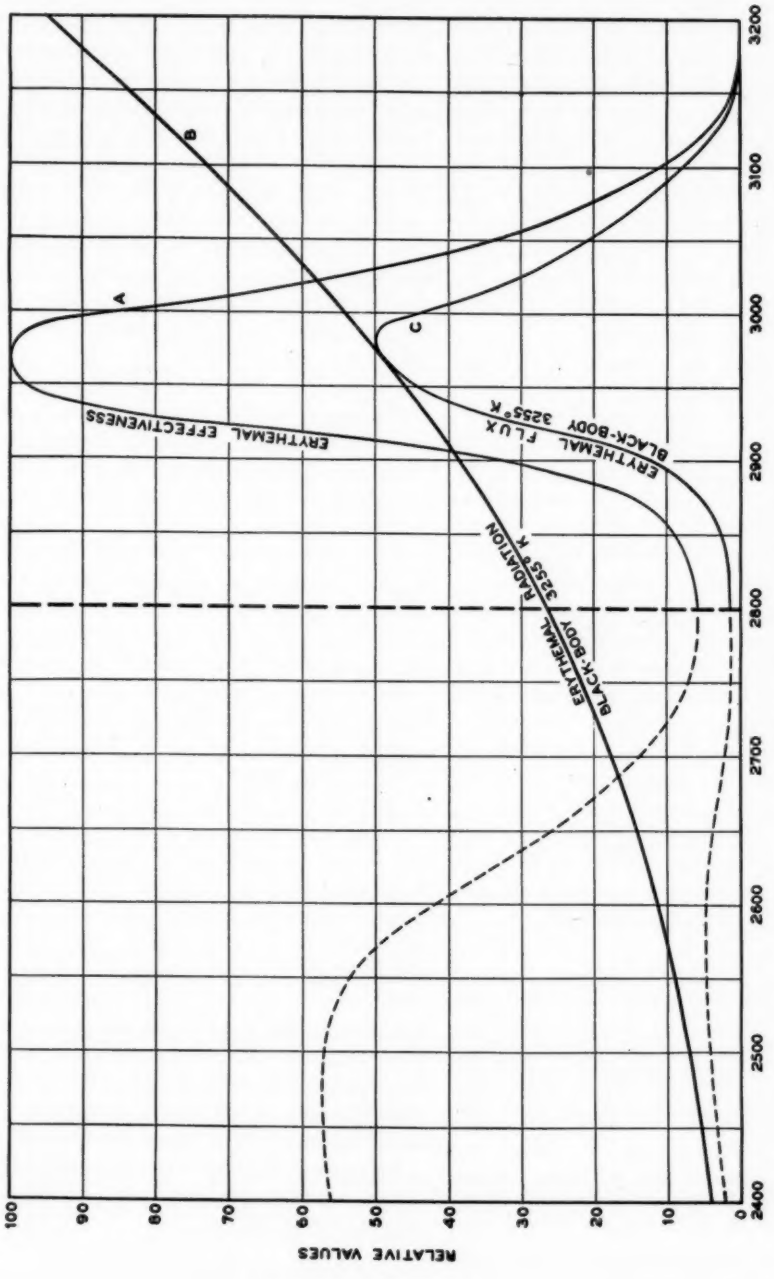

FIG 1. (A) Relative erythemal effectiveness of ultraviolet radiation of various wave-lengths. (B) Spectral distribution of erythemal radiation from a 1-watt black-body at 3255°K radiating uniformly as a point source. (C) Spectral distribution of erythemal flux from the 1-watt black-body source at 3255°K. This is erythemally weighted for each wave-length and is obtained by multiplying each value in A by the corresponding value in B.

necessary to standardize the lapse of time between exposure and examination. A convenient procedure is to expose the skin in the afternoon and examine it the next morning. The upper arm, chest and middle of the back are convenient places which are usually untanned. The determination of average untanned skin involves a great many exposures of various areas of skin on quite a number of persons. It is then possible to choose certain subjects who, combined, represent a fair average. Even one person may be found satisfactory for much work which does not require high accuracy or which is merely concerned with *relative* erythemal effectiveness.

After adequate study of the spectral sensitivity of human skin, purely physical methods of measuring erythemal effectiveness can be developed. The most recent extensive studies have been made by Coblentz[6] and his colleagues and by A. H. Taylor,[7] who has developed a portable instrument of high sensitivity.

From many measurements and computations it appears that not less than 180,000 ergs of radiation of maximum erythemal effectiveness (or the energy of each wave-length weighted according to the spectral effectiveness indicated in Fig. 1) are required to produce an MPE on most untanned skins. Usually 200,000 to 300,000 ergs are required for untanned skins which have not been severely tanned for several years. At present, according to our experience and criteria, we have chosen the value of 250,000 ergs of properly weighted radiation between λ2800 and λ3200 as representative of the exposure necessary to produce an MPE on average untanned skin.

Erythemal flux

Visible radiation is unweighted radiation in the visible spectrum. By analogy, erythemal radiation is unweighted radiation in the spectral range of erythemal effect. Total visible or erythemal radiation is the integrated radiation over the proper spectral range.

[6] W. W. Coblentz, R. Stair and J. M. Hogue, *Test of a Balanced Thermocouple and Filter Radiometer as a Standard Ultraviolet Dosage Intensity Meter*, Bur. Standards J. Research **8**, 759 (1932).

[7] A. H. Taylor and Geo. P. Kerr, *A Direct-Current Amplifier with Good Operating Characteristics*, Rev. Sci. Inst. **4**, 28 (1933); A. H. Taylor, *The Measurement of Erythemal Ultraviolet Radiation*, J. Opt. Soc. Am. **23**, 60 (1933).

Luminous flux is visible radiation weighted according to the spectral "visibility curve," that is, according to the effectiveness of each wave-length in producing the sensation of brightness or luminosity. By analogy erythemal flux is erythemal radiation weighted according to the effectiveness of each wave-length in producing erythema.

Therefore, throughout this paper *erythemal flux should mean radiation erythemally weighted* according to Fig. 1 and Table I. Total erythemal flux in microwatts, for example, integrated throughout the erythemal spectrum is equivalent, in the production of erythema, to the same number of microwatts of radiation of maximum erythemal effectiveness. In Fig. 1 the total erythemal flux from a 1-watt black-body source operating at 3255°K is determined by multiplying the intensity of each wave-length by the erythemal effectiveness of radiation of that wave-length, and integrating throughout the erythemal region.

For sunlight and radiation from artificial sources for general use as substitutes for sunlight, the erythemal radiation is confined chiefly to the long-wave part of the erythemal spectrum, that is, from λ2800 to λ3200. This is also true for carbon and quartz mercury arcs when properly filtered for this purpose. However, our fundamental units and terms are applicable to any source or equipment.

Although the short-wave portion of the "curve" of erythemal effectiveness, shown in Fig. 1, is not as stable or as well established as the long-wave portion, this fact is of minor importance in defining the unit source of erythemal flux. It is obvious, in Fig. 1, that the spectral distribution of energy from the 1-watt black-body source automatically suppresses the importance or influence of the short-wave portion. However, this does not penalize erythemal effectiveness of short wave ultraviolet from sources which supply it. It is advantageous that the source which we have chosen for a theoretical and fundamental standard emits most of its energy in the part of the erythemal spectrum which is best established at present.

Unit of erythemal flux

This is analogous to the lumen. For general use, an *erythemal viton* may be briefly designated

as an E-viton. Consideration of the magnitudes of erythemal units has been necessary in connection with sunlight and with commercial sources particularly those used in so-called sunlamps and dual-purpose lighting. The latter involves the addition of safe and adequate ultraviolet radiation, between λ2800 and λ3200, to the light used for lighting purposes.

Tentatively, we are defining the E-viton, or unit of erythemal flux, as 10 microwatts or erythemal flux. Of course, this means 10 microwatts after being erythemally weighted and is equivalent to 10 microwatts of erythemal radiation of maximal erythemal effectiveness. The microwatts of erythemal flux are obtained as in Fig. 1 by multiplying the number of microwatts of radiation in each elementary spectral band by its corresponding erythemal effectiveness and then properly summing or integrating these products. The integrated result in microwatts divided by 10 gives the number of E-vitons of erythemal flux.

Inasmuch as the emission of ultraviolet radiation by arcs is considerably influenced by the temperature, it is generally appreciably different when such sources are operated in and out of reflecting equipment, respectively. This difference is slight for tungsten-filament lamps; therefore, they may be more satisfactory for secondary standards. At present, so-called Mazda CX lamps are tungsten filaments operating at slightly higher temperatures than ordinary lamps and are surrounded by a bulb of glass which transmits erythemal radiation. The outputs of erythemal flux from tungsten-filament (Mazda CX) lamps with bulbs of so-called Corex D glass of an average thickness of 1 mm are shown in Table II.

TABLE II. *Erythemal flux from bare tungsten-filament lamps having bulbs of Corex D glass.*

	500-Watt	60-Watt
Color-temperature, °K	3025	2825
Lumens per watt	21.2	13.4
Total output of E-vitons	3200	140
E-vitons per watt	6	2.2
Finsens at 30 cm or 1 ft.	0.28	0.012

Unit source of erythemal flux

By analogy with the lumen, the unit source of erythemal flux emits one E-viton in each steradian or a total of 4π E-vitons. A name for such a unit source is not urgently needed, but, if desired, it might be termed a *radion*. Perhaps better still, it might be specifically termed an E-radion, thereby reserving the term *radion* for any source of radiation and distinguishing any specific use of its radiation by the prefixed letter.

It is found that a 1-watt black-body source operating at about 3255°K should emit one E-viton in every steradian or a total of 4π E-vitons. This is a temperature of a solid radiator readily attainable. In fact, a tungsten filament in a quartz bulb or a Mazda CX lamp could be a satisfactory secondary standard. The erythemal flux emitted by 1-watt black-body sources of various temperatures is indicated in Table III.

TABLE III. *Data pertaining to 1-watt black-body sources emitting radiation uniformly in all directions.*

Temperature (°K)	3255	4200	6480
Microwatts of erythemal flux:			
Total	125.7	1257	12570
Per unit solid angle	10	100	1000
Total lumens	27	55.5	85
Mean spherical candlepower	2.15	4.41	6.76

Unit intensity of erythemal flux

This is the analogue of the footcandle or, more properly, the phot. It would be one E-viton per sq. cm. A name for this term is needed and we have suggested *finsen* in honor of a recognized pioneer in therapeutic applications of ultraviolet radiation. According to the magnitude of the E-viton, which we have tentatively chosen, a finsen is 10 microwatts of erythemal flux incident upon a projected area of one centimeter. Of course, if the finsen were similarly used for other effects, the unit for intensity of erythemal flux would be designated as an E-finsen.

Average untanned skin must be exposed about 20 minutes to midsummer sunlight at sea level on a clear day at noon in order to obtain a minimum perceptible erythema (MPE). The intensity of erythemal flux in this case is about 18 microwatts per sq. cm or 1.8 finsens.

Unit of intensity of exposure

This unit logically becomes one finsen for one second. In accordance with the magnitude tentatively selected for the E-viton, the unit intensity

of exposure is 10 microwatt-seconds per sq. cm or 100 ergs of erythemal flux per sq. cm. Various measurements and computations indicate that at least 200,000 ergs of erythemal flux per sq. cm are necessary to produce an MPE (minimum perceptible erythema) on average untanned skin. Our best estimate at present is 250,000 ergs per sq. cm. This is equivalent to 2500 finsen-seconds or 42 finsen-minutes or 0.7 finsen-hours.

Unit of exposure or "dosage"

This is the result of an exposure to one E-viton for one second or one E-viton-second. This unit of exposure is equivalent to 10 microwatt-seconds or 100 ergs of erythemal flux. When the intensity of exposure is known, the total exposure in E-viton-seconds is obtained by multiplying the intensity of exposure in finsen-seconds by the exposed area of the receiving surface in square centimeters. In the prevention and cure of rickets the area of exposed skin is a factor, although its relationship to the final results is not known with accuracy. From a series of experiments on the cure of rickets in children, which has been conducted for several years by Dr. H. J. Gerstenberger[8] and colleagues for the purpose of establishing the threshold dosage, the most recent results show that about 12 percent of an MPE exposure daily cures severe rickets in babies almost fully clothed or with projected skin areas of about 500 sq. cm. This corresponds to about 150,000 E-viton-seconds per day or 42 E-viton-hours per day. Possibly even smaller dosages will be found effective and at least it may be established eventually that specific exposures need not be applied every day. If this is true, the total effective dosage may be less than the present summary of daily exposures.

Efficiency of source

Luminous efficiency is expressed in lumens per watt. Any source of biologically-effective radiation can be rated in vitons per watt. Erythemal efficiency of a source would be expressed in E-vitons per watt.

In Table IV is presented a brief summary of erythemal units, terms and magnitudes developed in the present paper, not only because they are needed or are useful, but also because they illustrate a procedure sorely needed in connection with other biological effects of radiation.

TABLE IV. *Summary of proposed erythemal units and terminology.*
(The E-viton is tentatively defined as 10 microwatts of erythemally weighted radiation or, more briefly, 10 microwatts of erythemal flux.)

Unit	Name	Magnitude
Unit erythemal flux	E-viton	10 microwatts of erythemal flux
Unit erythemal source	(Radion)	4π E-vitons
Unit intensity of erythemal flux	Finsen	One E-viton per sq. cm
Unit intensity of erythemal exposure	Finsen-second	One E-viton per sq. cm for one second
Unit erythemal exposure	E-viton-second	One E-viton for one second
Erythemal efficiency of source	E-vitons per watt	One E-viton per watt
Mechanical equivalent of one sq. cm of minimum perceptible erythema	Mechanical equivalent of erythema	About 2500 E-viton-seconds per sq. cm or 2500 finsen-seconds

SOME APPLICATIONS

In Table II data are presented for tungsten-filament lamps in bulbs of special glass. These Mazda CX lamps are promising practical standards of ultraviolet radiation longer than $\lambda 2800$. The data in Table II are for bare lamps. In Table V various data are presented for sources in oxidized aluminum reflectors, which are a part of regular commercial equipment. Obviously, some of the values in Table V depend upon the contour and reflection-factor of the reflector. However, because of the difficulty of accurately specifying these equipments, no attempt will be made to describe them. The source is of chief interest in connection with the primary purpose of this paper, which is to support our previous proposal of a fundamental system of units and

[8] H. J. Gerstenberger and A. J. Horesh, *The Cure of Infantile Rickets with Tungsten-Filament Radiation*, J. Am. Med. Assn. 97, 766 (1931).

TABLE V. *Data pertaining to extremely different sources of visible and ultraviolet radiation operating normally in oxidized aluminum reflectors with axes vertical.*

(Erythemal data are for average untanned skin.)

	Mazda Sunlight		*Mazda CX*	
	Type S-1	Type S-2	500-Watt	60-Watt
Total lumens emitted by equipment	6500	1170	8400	700
Total watts of equipment	440	158	535	64
Lumens per watt of equipment	14.8	7.4	15.7	11
*Footcandle-minutes for MPE	3600	5500	150,000	250,000
Total output of erythemal flux:				
Microwatts	700,000	82,000	22,000	1100
E-vitons	70,000	8200	2200	110
Intensity of erythemal flux per 100 footcandles:				
Microwatts per sq. cm	11.6	7.5	0.28	0.17
Finsens	1.16	0.75	0.028	0.017
Intensity of erythemal flux on axis of lamp and reflector at 30 in. from source:				
Microwatts per sq. cm	105	15	5.0	0.25
Finsens	10.5	1.5	0.5	0.025
Minutes exposure for MPE at 30 in.	4	28	83	1670
Erythemal efficiency of equipment:				
Microwatts of erythemal flux per watt	1600	520	41	17
E-vitons per watt	160	52	4.1	1.7

* For midday summer sunlight on a clear day at sea level about 20 minutes or 180,000 footcandle-minutes produce an MPE on average untanned skin.

terms. The practical results in Table V aid in appraising the proposals made, particularly in considering the desirable magnitude of the E-viton. This can be easily altered by changing its tentative value from 10 microwatts of erythemal flux to some other value.

The ultraviolet output of Types S-1 and S-2 Mazda Sunlight lamps varies considerably as is common for arcs. It is also affected by the position of operation as well as by the ventilation of the reflector. The values given in Table V are for normal operation with the axis of the lamp and reflector vertical. At an angle of 45 degrees, for example, the output in E-vitons is reduced nearly 50 percent.

Inasmuch as there is a definite relationship between the output of lumens and vitons for a given condition, data pertaining to both are presented. As a practical expedient of adequate accuracy in the present state of knowledge, the rating of sunlamps and the specification of dual-purpose lighting[1] (in which sources of light also provide ultraviolet radiation approximating the spectral range of sunlight) have been established upon an erythemal basis. Exposures in footcandle-minutes, which produce an MPE on average untanned skin, are known for the equipment to be used and this is a guide in making recommendations. A general substitution of the E-viton and other proposed units and terms would place commercial and professional usage of artificial sunlight on a still better basis.

The Type S-1 Mazda Sunlight lamp is a powerful source of erythemal radiation and the 60-watt Mazda CX is a relatively weak one. Both are in practical use. From an examination of the magnitudes of the various values in Table V for these two sources an idea of the practicability of the tentative magnitude of the E-viton is gained. If the magnitude of the E-viton were increased tenfold, to 100 microwatts of erythemal flux (erythemally weighted radiation), its magnitudes and that of the finsen would still be practicable. However, the erythemal efficiencies of the weak sources would have to be expressed by quantities less than unity. It would also require that the 1-watt black-body standard source have a temperature of 4200°K. This is far out of the range where a tungsten-filament could be used as a practical standard source and it appears that the tungsten-filament can fill this need better than any other source at the present time. It could be placed in a bulb of suitable glass and measurements of intensity could be made in a given direction or of the total erythemal flux by an integrating method.

Therapy

In therapeutic practice it is desirable to be able to predetermine the intensity of exposure which will produce a minimum perceptible erythema (MPE) on average untanned skin. Then the dosage can be predetermined approximately for any given case. If the intensity of exposure per sq. cm of skin which will produce an MPE be W ergs of erythema flux, and if the intensity of erythemal flux at the surface of the skin be I microwatts per sq. cm, the duration of exposure necessary eventually to produce an MPE would be $t=(W/10I)$ seconds. The value W for untanned skin varies considerably. Assuming the tentative average value of 250,000, the necessary duration of the exposure would be

$$t=(25{,}000/I) \text{ seconds}=(417/I) \text{ minutes.}$$

Dual-purpose lighting

Inasmuch as this new field involves supplying biologically-effective ultraviolet radiation along with light for seeing, the new practice in its early stages is dominated by terminology and measurements of light. If the output of lighting equipment in lumens and vitons is known, the intensity of erythemal flux may be determined by means of an ordinary photometer. In an actual installation allowances must be made for reflecting surfaces beyond the lighting equipment, such as ceiling and walls, which generally reflect ultraviolet less efficiently than visible radiation. However, in lighting practice this can readily be taken into account. Furthermore, with the advent of portable instruments[7] for measuring erythemal flux, the results of any given installation can be directly measured. As in the case of lighting practice, experience based upon measurements provides the necessary allowances.

In dual-purpose lighting excessive exposure of the skin to ultraviolet radiation must be avoided. Apparently the maximum dosages necessary for so-called health-maintenance are only fractions of an MPE dosage. Little is known definitely about the benefits of erythemal radiation to so-called healthy persons, but an impressive case can be constructed. However, dual-purpose lighting merely purports to provide at all times, through artificial lighting, whatever beneficence there is in summer sunlight. Rickets provides the most reliable and convincing means of measuring effectiveness of erythemal radiation, but, of course, the dosage required to prevent or cure rickets is not necessarily a measure of the dosage required by healthy adults, if indeed they need any dosage. However, dosages established by experiments with rachitic children give something to work on. It has been found that daily dosages equivalent to about 0.1 MPE on average untanned skin cure severe rickets in babies almost fully clothed. Probably it requires even less to prevent rickets, that is, to maintain health. Such data have led to the conclusion that for so-called healthy persons, normally clothed, a sufficiently large dosage of ultraviolet radiation could be obtained during the hours in which artificial lighting is required without producing an objectionable erythema.

In dual-purpose lighting, the minimum duration of exposure is determined by factors beyond the control of the designer unless the ultraviolet component is separately controllable. In average work-places throughout most of the year artificial lighting is in use several hours daily. Obviously, in some places it is in use all day and in others only a short time. In the case of workers their hours are established; in the case of transients, such as shoppers in stores, this is not true. Thus, dual-purpose lighting becomes chiefly of interest to those who spend fairly definite periods under artificial light.

Time is an important factor in the case of the ultraviolet component of dual-purpose lighting. In the initial stages of development of this new contribution of artificial lighting, it was practicable and even necessary to express intensity of erythemal flux in terms of intensity of illumination (footcandles) and of the duration of exposure (minutes) to produce an MPE on average untanned skin. These necessary footcandle-minutes, abbreviated to FCM, can be determined for a given installation if the output of the lighting unit in lumens and vitons is known.

Let W be the number of ergs or erythemal flux per sq. cm required to produce an MPE on average untanned skin, L the lumens output of a lighting fixture, and FCM the footcandle-minutes. The total erythemal flux B emitted by the light-

ing fixture is

$$B = (929WL/600(\text{FCM})) \text{ microwatts.}$$

If W be equal to 250,000 ergs per sq. cm,

$$B = (387{,}000L/(\text{FCM})) \text{ microwatts}$$
$$= (38{,}700L/(\text{FCM})) \text{ E-vitons.}$$

In like manner the intensity of erythemal flux I per footcandle (FC) is

$$I/(\text{FC}) = (B/929L) \text{microwatts per sq. cm}$$
$$= (B/92.9L) \text{ finsens.}$$

By use of these formulae, the output of erythemal flux from a given lighting fixture may be converted from the data involving lumens and FCM for an MPE into the new units and terms. For a table of such data on lighting equipment, the details of a dual-purpose lighting-system may be readily computed. For example, an installation of dual-purpose lighting, designed to supply the equivalent of 0.1 of an MPE dosage on average untanned skin where artificial lighting is in use 3 hours daily, must supply 21.4 E-vitons per square foot.

Computations of the intensity of illumination in footcandles necessary to produce a fraction R of an MPE on average untanned skin in H hours can be based on the following equation:

$$\text{Footcandles} = (R929WL/3600HV) = R645L/VH,$$

where V and L are the outputs of a lighting fixture in E-vitons and lumens, respectively, and W is the assumed value of 25,000 microwatt-seconds per sq. cm, or 2500 E-viton-seconds per square centimeter.

This paper is to be considered as a presentation of a complete system which is sorely needed for many different effects of radiation. The suggested terms and other details are the results of much experience, particularly with ultraviolet radiation. However, these are naturally subject to a consensus of opinion of all interested. It is emphasized that, although erythemal units and terms are of importance in themselves, they also serve the greater purpose of supplying an analogy for a system of units and terms for any other effect of radiant energy.

Studies in Refractive Index. I and II

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In Part I four methods are described for measuring the refractive index of strongly absorbing liquids. The first two of these depend upon determination of the critical angle of reflection of monochromatic light at a glass-liquid interface. In the third, white light was reflected at angles near the critical angle and was then allowed to enter a spectrograph. Microdensitometer records were made of the resulting spectrograms. Peaks in the record correspond to maxima of the refractive index. In the fourth method the transmitted light was examined visually in a spectroscope. In Part II these methods have been applied to a saturated aqueous solution of potassium permanganate. As a result a dispersion curve was found with a strong anomaly centering about 5473A and in addition a series of minor anomalies corresponding to the banded structure of the absorption spectrum. It is concluded that the band at 5473A is that caused by the fundamental frequency of an electronic transition in the manganese atom.

PART I. METHODS OF MEASUREMENT

Introduction

THE measurement of refractive index in regions of strong absorption has long been of interest by reason of the check which the accumulation of such data affords upon the theory of dispersion. When the quantum theory replaced the classical theory, Slater, Bohr, Kramers and others[1] showed that the form of the dispersion equations remained unchanged but that the probabilities of transition between various energy levels replaced the intensity factors formerly interpreted as due to the numerical distribution of the resonators of each particular frequency.

Measurement of the refractive index near regions of so-called anomalous dispersion still has sufficient general interest to justify the development of experimental technique. In addition, as will be referred to in Part II information was needed for the particular case of potassium permanganate.

In the past Pflüger,[2] Stöckl,[3] Wood and Magnusson[4] have studied the dispersion of materials within an absorption band by the use of thin prisms. Fricke[5] and Cartmel[6] have used interference methods, and Lowry and Allsopp[7] have devised a method which makes use of interference fringes produced within a quartz étalon containing the liquid under examination.

In the present investigations four methods have yielded information as to the behavior of the dispersion curve within the region of absorption. Three of these are modifications of methods previously used by others, not necessarily however in the region of anomalous dispersion, while one is believed to be entirely new. The latter is described as method No. 3.

Method 1

This method has been suggested by R. S. Clay[8] and has been used in a modified form for transparent substances in the ultraviolet by L. C. Martin.[9] It consisted in a determination of the critical angle of refraction from glass to the medium under examination. This was done by putting two right-angled isosceles prisms together with a thin film of the material enclosed between their hypotenuse faces (Fig. 1). The pair of prisms P was placed on the table of a spectrometer capable of being read to 20″ of arc. The collimator of this spectrometer was illuminated by monochromatic light by means of a double monochromator, which consisted of two ordinary

[1] Bohr Kramers and Slater, Zeits. f. Physik **24**, 69 (1924). Kramers, Nature **114**, 310 (1924). Slater, Phys. Rev. **25**, 395 (1925).

[2] Pflüger, Ann. d. Physik **65**, 173, 225 (1898).

[3] Stöckl, *Dissertation, Munich*, 1900.

[4] Wood and Magnusson, Phil. Mag. **1**, 36 (1901).

[5] Fricke, Ann. d. Physik **16**, 865 (1905).

[6] Cartmel, University of Nebraska Studies **3**, 101 (1903).

[7] Lowry and Allsopp, Proc. Roy. Soc. **A126**, 165 (1929); **A133**, 26 (1931).

[8] Clay, *Treatise on Practical Light*, p. 136.

[9] Martin, Trans. London Opt. Soc. **29**, 1 (1927).

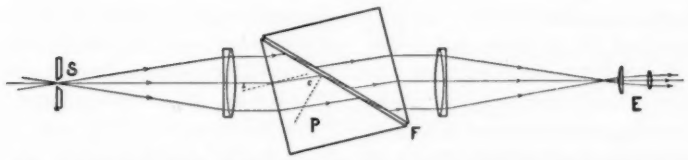

FIG. 1. *S*, exit slit of double monochromator; *P*, prisms on the spectrometer table; *F*, film of liquid between the prisms; *E*, eyepiece focussed on the slit *S*.

constant deviation spectrometers arranged so that the entrance slit of the second formed the exit slit of the first.

A 250 watt tungsten filament projection lamp was used as a source of white light. The whole system, double monochromator and spectrometer, was focussed for the 5461A green line from a mercury arc, and so adjusted that the wave-length drums read correctly throughout the spectrum. The achromatism of the lenses of the monochromators and spectrometer was such that the system remained sensibly in focus throughout the most important part of the spectral range, which in the case of measurements upon potassium permanganate, was from about 4800A to 6000A. All the slits were kept at the same equivalent width, which was 15A in the green, and proportionally less at shorter wave-lengths.

Measurements were made by first setting both wave-length drums so that monochromatic light of any desired wave-length illuminated the entrance slit of the spectrometer. This light, after collimation, fell upon the pair of prisms, and provided that the angle of incidence on the film enclosed between the hypotenuse faces was less than the critical angle, it could be observed in the telescope *E*. Rotation of the spectrometer table caused this angle of incidence to increase until at the critical angle the illumination in the telescope was finally extinguished. Herschel-Ketteler interference bands were observed as the critical angle was approached and the last of these bands was replaced by uniform extinction as long as the thickness of the film of liquid between the prisms was greater than one or two wave-lengths.

A determination of the angle of incidence of the collimated monochromatic light upon the first prism at the critical position of extinction enabled the refractive index of the liquid to be calculated in terms of that of the glass prisms. This latter was measured for eight lines in the mercury spectrum and the values plotted against wave-length. The index of the glass for any particular wave-length could be interpolated from this curve with an accuracy of one unit in the fourth decimal. In order to make readings of refractive index of a liquid with similar accuracy it is necessary to control the temperature. The apparatus was therefore rigidly mounted in a room of which the temperature was kept constant at 23°C with an error of $\pm 0{\cdot}1$°C. A heating coil taking some 30 amperes at 220 volts was strung round the walls of the room and the current was controlled by a relay actuated by a thermostat which was placed close to the prism table of the spectrometer.

Some apprehension was felt that in regions of strong absorption the method would give untrustworthy readings as it was feared that extinction might be due to absorption rather than to cut off at the critical angle. However, the final analysis of all the results (Part II) shows that this is not so. The minimum of refractive index as measured by this method, occurs in all cases on the short wave-length side of the appropriate absorption band, and not at the maximum of absorption as would be the case if extinction were due to absorption rather than to true reflection at the critical angle.

In spite of other possible errors the method seems trustworthy for two reasons. Firstly, that the results are tolerably consistent amongst themselves no matter who the observer or whether the readings are taken proceeding in an orderly fashion throughout the spectrum or not. Secondly, the results obtained agree remarkably well, considering the difficulties encountered, with those of the three other methods to be described.

Method 2

Although the method just described is believed to give the most reliable and extensive results, it unfortunately suffers from a defect which is both

physiological and psychological in that it necessitates the determination of an extinction point. Consequently it is open to objections on the score of variation of visual sensitivity, of variation of absolute intensity of the source with wavelength, and perhaps the most serious of all, of the variation of intensity of the light reaching the observer's eye because of absorption by the material under examination.

A method was therefore developed which employed a photometric method of matching against a standard the intensity of the light reflected at the critical angle. It was noticed while this paper was in preparation for the press, that the photometric method has great similarity to that described by Guillery.[10] It suffers from a defect noted by him, that the reflection coefficient is lowered in regions of strong absorption, with consequent error in photometric matching of the reflected beam. This phenomenon is actually utilized to advantage in method 3.

Method 2 depends upon the fact that the reflection coefficient at a glass-liquid surface becomes in general equal to unity at the critical angle, and the increase at this angle is very abrupt. This is not true, however, when the absorption coefficient in the second medium becomes large. Even beyond the critical angle there is a disturbance in the second medium, and some energy enters the latter, although the amplitude of the disturbance falls off exponentially with distance, very rapidly. If the second medium is transparent a steady condition is set up and all the incident energy is found in the reflected beam. If it has a comparatively large absorption coefficient, energy is absorbed and only the residue appears in the reflected beam, with the result that the reflection coefficient never reaches unity and only approaches this value as the angle of incidence becomes much greater than the critical angle.

An attempt to overcome this difficulty was made by using a field in which photometric equality could be produced in the following manner.

A single prism of 60° angle and refractive index 1.5147 for sodium light was silvered on one face. This face was ruled so that two strips of silver 2 mm wide were removed leaving clear surfaces separated by a 2 mm strip of silver.* The silvered surfaces were protected by electroplating them with rhodium. A drop of the liquid was placed on this ruled face and kept there by a small glass plate with a spacer 0.5 mm thick cemented to it. Capillary attraction was sufficient to keep the liquid in position in this cell.

The silvered surface of this prism as seen by reflected collimated light from the double monochromator was focussed with the aid of an auxiliary lens F (Fig. 2). The dividing lines between the silvered surfaces and the two clean strips were seen sharply. The measurements were made by

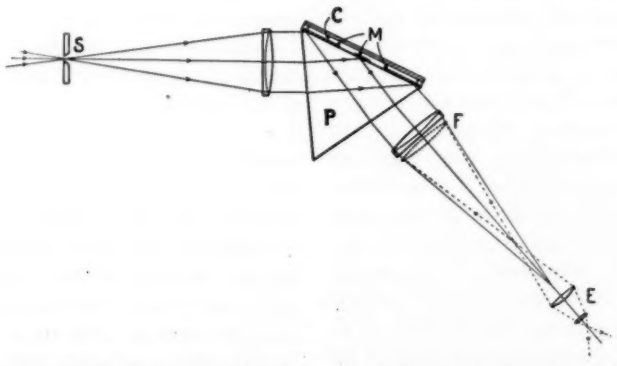

FIG. 2. S, exit slit of monochromator; P, prism on the spectrometer table; M, silvered surface—rhodium plated; C, cell containing liquid; F, auxiliary lens focussing on M; E, eyepiece viewing photometric field M.

[10] Guillery, Phys. Zeits. **31**, 700 (1930).

* For this we are indebted to the skill and patience of Mr. Gustave Fassin.

rotating the spectrometer table which carried the prism, until the photometric field was equally bright all over. The silver surface had a reflectivity of about 95 percent and consequently the position of photometric match did not give the full value of the critical angle, but an angle slightly less than this. By this means it was hoped to obtain a dispersion curve, which while it might be consistently too low, would indicate the relative course of the true curve.

Although the method was admirably successful outside an absorption band and provided a rapid and easy method of making the necessary settings, it was found untrustworthy within regions of strong absorption. Consequently this method of using a photometric match had to be abandoned, although it is an excellent one for less powerfully absorbing substances.

Finally however a total reflection setting was made by the following means. The cell at the back of the 60° prism (without silvering) was only half filled with liquid and the meniscus was observed in the low power microscope *FE* (Fig. 2). Provided that the angle of incidence was less than the critical angle interference fringes were seen in the edge of the meniscus (Fig. 3). These were caused by reflection from the back and front surfaces of the thin wedge shaped film of liquid in the meniscus, where the liquid-glass interface gave place to an air-glass interface. In regions of transparency a great number of fine interference bands could be seen, but even in the region of strongest absorption two or three could still be observed. Determination of the position of critical angle reflection consisted in rotating the spectrometer table until the last interference band disappeared. In regions of complete transparency this coincided with the position of photometric match between the two halves of the field.

FIG. 3.

The settings made by this method enabled calculations to be made of the refractive index of the liquid and the curve so obtained agreed in detail with that made by method 1. While relatively the two methods give similar results there was still a difference in absolute value of the refractive index, particularly in the region where the absorption was the strongest. In this region method 2 gave an apparently higher refractive index than method 1. It must be admitted that this is an inevitable result of the conditions of any experiment depending upon observation of the critical angle. Unfortunately interferometric methods are also subject to uncertainty when extinction coefficient rises to large values, and the present methods are not unique in this respect.

As the results of measurements by the two methods described gave a dispersion curve for potassium permanganate in aqueous solution, which exhibited a major anomaly with smaller anomalies superimposed, it was felt necessary to obtain some further check which would either confirm the existence of these minor anomalies or show them to be spurious and due merely to variation in absorption coefficient with wavelength. The third method was therefore developed.

Method 3

The reflection coefficient from a glass liquid interface is expressed by the Fresnel reflection formula

$$R=\tfrac{1}{2}\{\sin^2(r-i)/\sin^2(r+i) + \tan^2(r-i)/\tan^2(r+i)\}.$$

On differentiation of R with respect to wavelength λ it may be shown that for angles of incidence i less than the critical angle $dR/d\lambda=0$

when $dn/d\lambda = 0$ and also that $d^2R/d\lambda^2 = -Ad^2n/d\lambda^2$ where n is the relative refractive index at the interface and A is a positive constant.

Thus if the second medium is absorbing the refractive index is complex and the relative refractive index n_0 from glass to liquid may be expressed as $n_0 = n_{\text{liquid}}/n_{\text{glass}} = n(1-jk)$ where j is the root of minus one.

If light which is polarized in the plane of incidence be considered for simplicity, only the first term in the Fresnel formula need be used, and $R = \sin^2(r-i)/\sin^2(r+i)$ where $\sin i = n_0 \sin r$. If this be expanded and $\sin i$ replaced by $n_0 \sin r$, there results on dividing out by $\sin r$

$$R = \{(\cos i - n_0 \cos r)/(\cos i + n_0 \cos r)\}^2.$$

Now

$$n_0 \cos r = n_0(1-\sin^2 r)^{\frac{1}{2}} = (n_0^2 - \sin^2 i)^{\frac{1}{2}},$$

so that

$$R = \{(1-x)/(1+x)\}^2 \text{ where } x = (n_0^2 - \sin^2 i)^{\frac{1}{2}}/\cos i;$$

hence

$$\frac{dR}{d\lambda} = 2\left(\frac{1-x}{1+x}\right)\frac{d}{d\lambda}\left(\frac{1-x}{1+x}\right) = -4\,\frac{1-x}{(1+x)^3}\,\frac{dx}{d\lambda}.$$

Now

$$\frac{dx}{d\lambda} = \frac{n_0}{a(n_0^2-b^2)^{\frac{1}{2}}}\,\frac{dn_0}{d\lambda} = \frac{n_0}{a^2 x}\,\frac{dn_0}{d\lambda}$$

where a has been written for $\cos i$ and b for $\sin i$. Therefore

$$dR/d\lambda = -[4(1-x)n_0/a^2(1+x)^3 x](dn_0/d\lambda).$$

From this it follows that $dR/d\lambda = 0$ when $x = 1$ or when $n_0 = 1$ which is of no interest. The remaining condition that is possible is that $dR/d\lambda = 0$ when

$$[(1-x)n_0/(1+x)^3 x](dn_0/d\lambda) = 0.$$

As n_0 is complex and therefore x is complex this condition does not admit of an easy solution.

However nk is relatively small; e.g., for potassium permanganate in saturated aqueous solution nk is always less than 10^{-2}. Consequently no serious error will be made in considering the real part only of $dn_0/d\lambda$. To this degree of approximation therefore $dR/d\lambda = 0$ when $dn_0/d\lambda = 0$ and if $n_0 = n(1-jk)$ this occurs when $dn/d\lambda = 0$.

Now

$$\frac{d^2R}{d\lambda^2} = -\frac{4(1-x)}{(1+x)^3}\,\frac{d^2x}{d\lambda^2} - \left(\frac{dx}{d\lambda}\right)^2 \frac{d}{dx}\left\{\frac{4(1-x)}{(1+x)^3}\right\}$$

but when $dn_0/d\lambda = 0$ $dx/d\lambda$ is also zero therefore

$$d^2R/d\lambda^2 = -[4(1-x)/(1+x)^3](d^2x/d\lambda^2),$$

and as

$$dx/d\lambda = [n_0/a(n_0^2-b^2)^{\frac{1}{2}}](dn_0/d\lambda)$$

$$\frac{d^2x}{d\lambda^2} = \frac{1}{a^2 x}\left\{\left(1-\frac{n_0}{a^2x^2}\right)\left(\frac{dn_0}{d\lambda}\right)^2 + n_0\,\frac{d^2n_0}{d\lambda^2}\right\};$$

but $dn_0/d\lambda = 0$, so that

$$d^2R/d\lambda^2 = -[4(1-x)n_0/(1+x)^3 a^2 x]d^2n_0/d\lambda^2.$$

Now if the angle of incidence i is less than the critical angle $\sin i < n$ and the real part of x is positive and since $n < 1$ the real part of x is less than one and the real part of $(1-x)$ is positive.

Consequently, $d^2R/d\lambda^2$ is of opposite sign to $d^2n/d\lambda^2$ and therefore a maximum of n corresponds to a minimum of R.

The significance of this is that if white light be reflected from a glass-liquid interface at an angle of incidence less than the critical angle, dark bands will occur in the spectrum, and these will correspond in wave-length to the position of maxima of refractive index. Similarly the bright bands in the spectrum will correspond to minima of refractive index.

In order to magnify this effect a rhomb of glass was used (Fig. 4), to the long faces of which small cells were cemented; these were filled with the liquid to be examined. This rhomb was placed on the table of a spectrometer and illuminated by collimated white light. The angle of incidence could be changed simply by rotating the spectrometer table, and because four reflections occurred within the rhomb, the light emerged always parallel to its original direction. It was then focussed on to the slit of a spectrograph and the spectrum observed both visually and photographically. A comparison spectrum was also photographed at the same time. This was produced by light from the same source which was passed through an absorption cell also containing the liquid under examination. Reference lines were superimposed on both spectra by adding

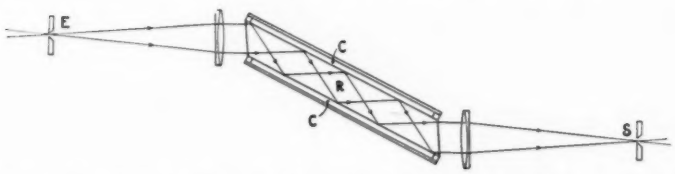

FIG. 4. *E*, entrance of white light; *R*, rhomb for multiple reflection; *C*, cells containing liquid; *S*, entrance slit of spectrograph.

light from a mercury arc to that from the white source.

The spectra obtained from saturated aqueous solutions of potassium permanganate are shown in positive in Fig. 5, where it may be seen that

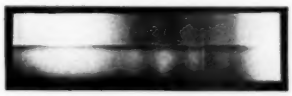

FIG. 5. Upper, absorption spectrum; Lower, reflection spectrum at angle less than critical.

the dark bands of the reflection spectrum are displaced to the long wave-length side of the corresponding absorption bands. This is further shown by the microdensitometer record* in Fig. 6.

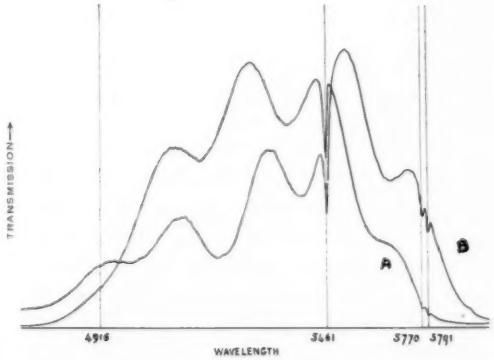

FIG. 6. Microdensitometer record of the photographic negative of Fig. 5. *A*, of absorption spectrum; *B*, of reflection spectrum at angle less than critical.

Moreover the microdensitometer record shows that the reflection coefficient has its least value to the long wave-length side of the absorption band at 5473A whereas the absorption coefficient has the highest maximum at 5255A.

For comparison the spectra were also photographed when the angle of incidence was greater

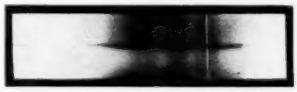

FIG. 7. Upper, absorption spectrum of the photographic negative of Fig. 7; lower, reflection spectrum at angle greater than critical.

than the critical angle (Fig. 7). The minima of reflection now coincide with the maxima of absorption (Fig. 8).

Wave-lengths of the maxima and minima of the reflection spectrum photographed at angles of incidence less than the critical angle, were computed by means of a Hartman interpolation

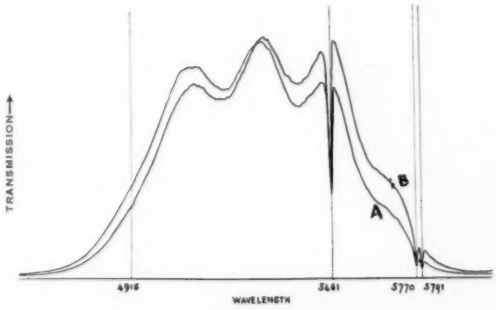

FIG. 8. Microdensitometer record: *A*, of absorption spectrum; *B*, of reflection spectrum at angle greater than critical.

formula from the microdensitometer record. The interpolation was checked against measurements made visually on the spectrum seen directly, by the use of a filar micrometer eyepiece. The agreement was perfect.

* For the making of this record we are indebted to the kindness of Dr. O. Sandvik.

The wave-lengths of the bands in the reflection spectrum were also determined visually by setting what appeared to the eye to be the center of each band in turn upon the cross wires and reading the wave-length from the calibrated drum.

While this method does not determine the value of the refractive index, it gives the wave-lengths at which maxima or minima occur and these provide a check upon the dispersion curves obtained by the other methods.

Method 4

This method is useful as a further check upon the previous measurements, and has already been described by Martin[9] for use with transparent liquids. It consists in using the two prisms of method 1 with collimated white light in place of monochromatic light. The transmitted light is then examined with a spectroscope. A spectrum crossed by dark bands is seen, which at angles of incidence far removed from the critical angle are simply the absorption bands, but at the critical angle are shifted to shorter wave-lengths to correspond with the minima of refractive index. As the critical angle for any particular wave-length is reached the spectrum at that wave-length is entirely extinguished and the last portions to disappear correspond to the wave-lengths at which occur the maxima of refractive index. In other words the bright bands in the spectrum correspond to maxima of refractive index, the converse of the spectrum obtained in method 3.

The observations have to be made visually (Martin who made them photographically was working with transparent substances) and are tedious, and in regions of strong absorption are probably less accurate than those made by the other methods.

Part II. The Anomalous Dispersion of Potassium Permanganate in Aqueous Solution

A number of observers have noticed that the absorption spectrum of the permanganates shows a banded structure in the visible region, and that these bands are equally spaced on a frequency scale. Slightly different values of the constant wave number separation of the bands have been given by different observers. The results of Hantzsch and Clark[11] give a mean value of 748 cm^{-1}, of Hagenback and Percy[12] a figure of 741 cm^{-1}. Adinolfi[13] from photographic observations obtained a value of 753 cm^{-1} while Taylor[14] also from photographic observations found a wave number separation of 744 cm^{-1}. All observers agree in stating that the third band counting from the red, at about 5255A is the one of greatest absorption. Formánek[15] states that the second band at 5473A is the one which alone persists at very great dilution and argues from this that it is the principal band. Taylor[14] showed that the wave number separation of the bands increases in a non-ionizing solution, and that in the crystalline state it becomes 797 cm^{-1} which corresponds to a frequency of vibration of the manganese atom. This is found in the infrared absorption spectrum at a wave-length of 12.7 μ or 788 cm^{-1}.

The frequency ν of any absorption band in the visible region may be expressed as $\nu = \nu_e + n\nu_r$ where ν_r is the infrared frequency of oscillation of the manganese atom within the MnO_4^- group, ν_e is the frequency of the principal band, and n is integral or zero. ν_e is the frequency resulting from an electronic transition in the manganese atom. The question arises whether n can be negative. This can only happen if the absorption is the result of a quantum transition from an energy level other than the ground state. If sufficient MnO_4^- ions exist in the first quantum state with energy $h\nu_r$ the corresponding band with $n = -1$ will appear in the absorption spectrum. Calculation of the probability of occurrence of such states shows that approximately 3 percent of the MnO_4^- ions will exist at room temperature in the first vibrational quantum state, and less than 0.1 percent will exist in the second. That is to say the value of n in the formula for the absorption bands will be limited to positive integers, zero and -1. In consequence the second band counting from the red, at a wave-length of 5473A should be the one which results from the funda-

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[11] Hantzsch and Clark, Zeits. f. physik. Chemie **63**, 374 (1908).

[12] Hagenbach and Percy, Helvetia Chem. Acta **5**, 454 (1922).

[13] Adinolfi, Atti. Accad. Lericei **29**, 38 (1920).

[14] Taylor, Trans. Faraday Soc. **25**, 860 (1929).

[15] Formánek, Die Qualitative Spectralanalyse, p. 133.

mental electronic transition in the manganese atom.

The frequency ν_s of this principal band should should provide the most important term in the Drude-Lorentz dispersion equation. It was therefore decided to measure the refractive index of potassium permanganate in aqueous solution throughout the region of strong absorption in the visible spectrum.

As described in Part I, the measurements were all made in a room of which the temperature was controlled by a thermostat at 23°C±0.1°C. The solution used was saturated at this temperature.

The solutions were made in the following way. Excess of chemically pure crystalline potassium permanganate was boiled with distilled water in a Pyrex flask for some hours, allowed to cool, and filtered through an unglazed porcelain filter of the Gooch type into an opaque brown glass bottle. An excess of permanganate crystals was added and the solution left for some days or longer at 23°C. It was occasionally shaken to ensure that complete equilibrium was reached.

The glass optical surfaces with which in the various methods of measurement, the solution was to come in contact, were carefully cleaned with chromic acid, and washed in constantly changed distilled water for ten minutes and wiped dry with a chamois leather.

In spite of all precautions a deposit of hydrated oxide of manganese was frequently produced on the optical surfaces especially towards the end of a long series of measurements. This deposit because it formed a transition layer of variable thickness and refractive index, made the observation of the critical angle indefinite. When such was the case, the critical angle was also found to alter with time as the deposit accumulated. Whenever this happened the readings were rejected and a new series commenced after the deposit had been cleaned away with dilute sulphurous acid, and the optical surfaces washed and dried.

The methods described in Part I of this paper were used and the results agreed in the main. These are tabulated in graphical form in Fig. 9.

ANALYSIS OF THE RESULTS

MAXIMA of REFRACTIVE INDEX
MAXIMA of ABSORPTION
MINIMA of REFRACTIVE INDEX
4700 4800 4900 5000 5100 5200 5300 5400 5500 5600 5700 5800 A
WAVELENGTH

FIG. 9.

The position of the maxima of absorption as determined by various observers are indicated by full lines. The positions on a wave-length scale of the maxima and minima of refractive index given by separate sets of readings made with method 1 are indicated by full lines, with method 2 by lines of half the height, with method 3 by 3/4 lines and with method 4 by 7/8 lines.

In each case the maxima are found to occur on the long wave-length side of the appropriate absorption band, and the minima on the short wave-length side, as required by the Drude-Lorentz formula. This is well shown in the figure, in spite of the scatter resulting from unavoidable experimental errors. There is no evidence that the minima of refractive index observed are in any way spurious, as was at first feared might be the case as a consequence of loss of intensity of light at the maximum of absorption.

The curve obtained by method 1 is chosen as most nearly representative of the true course of the dispersion curve, and is shown in Fig. 10. Readings were made every 50A over portions of the curve where the slope was fairly constant and every 25A where it was varying rapidly. The curve is not smoothed out in any way.

The dispersion curve obtained by method 2 by the observation of interference fringes in the meniscus, is shown in Fig. 11. As it is strongly influenced by the low reflecting power in the region of maximum absorption it is not considered for the present purpose.

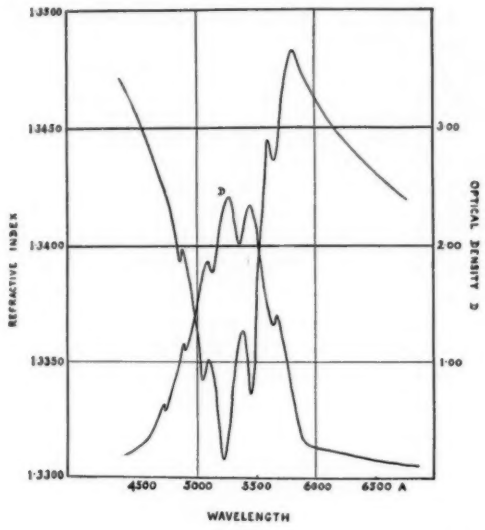


FIG. 10.

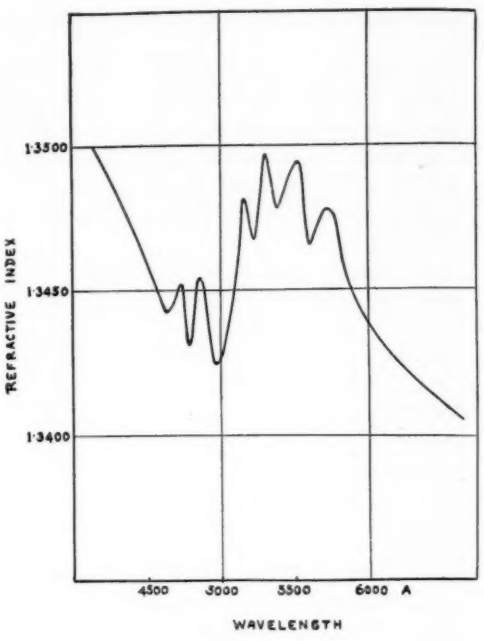


FIG. 11.

Approximate solution of the dispersion equation

It is clearly impossible to solve completely the Drude-Lorentz dispersion formula which would express the detailed structure of the refractive index curve, because there are some eight absorption bands in all, and the equations are too unwieldy.

If it be assumed that one of the terms in the dispersion equation has a much greater influence than any of the others, satisfactory approximations may be made. This term which is responsible for the major anomaly, must be that containing the fundamental electronic frequency ν_e; the combination frequencies must occur in the terms which are responsible for the minor anomalies. Consequently the curve of Fig. 10, if smoothed out to disregard the minor anomalies, can be considered to represent the Drude-Lorentz equation with a single term in the visible region, and this term is that containing ν_e the electronic frequency about which information is desired.

Now the dispersion equation with one term in the visible region is

$$\frac{\mu_0^2-1}{\mu_0^2+2}=b+\frac{Ne^2}{3\pi}\frac{1}{\{m(\nu_e^2-\nu^2)+j\beta\nu\}},$$

where μ_0 is the absolute refractive index of the solution, β is a damping factor and b represents the contribution of the terms in the infrared and ultraviolet. If the real and imaginary parts of this expression be separated there results

$$\frac{\mu_0^2-1}{\mu_0^2+2}=b+\frac{Ne^2m(\nu_e^2-\nu^2)}{3\pi\{m^2(\nu_e^2-\nu^2)^2+\beta^2\nu^2\}}-\frac{Ne^2j\beta\nu}{3\pi\{m^2(\nu_e^2-\nu^2)^2+\beta^2\nu^2\}}.$$

At the point $\nu=\nu_\epsilon$ this reduces to

$$(\mu_0^2-1)/(\mu_0^2+2)=b-jNe^2/3\pi\beta\nu.$$

If μ_0 be expressed as $\mu_0=\mu(1-j\kappa)$ where μ and κ are both real the imaginary parts of the expression above may be equated, and it follows that

$$\frac{6\mu^2\kappa}{\{\mu^2(1-\kappa^2)+2\}^2+4\mu^4\kappa^2}=\frac{Ne^2}{3\pi\beta\nu}.$$

Now the left-hand side of this equation can be calculated from experimental data.

Measurements on the absorption coefficient of potassium permanganate in aqueous solutions show that the Beer-Lambert law holds for moderate dilutions.[12] Also the absorption spectrum does not show any appreciable alteration with concentration. This was tested by comparison of two absorption spectra side by side in the same spectroscope, one from a 10 cm column of dilute solution and one from a saturated solution in a layer so thin that the optical density was comparable to that of the long column. The two spectra appeared to be identical.

The value for the maximum optical density D of a solution of concentration c_1 of 0.0164 gram of permanganate per liter, was measured for a 10 cm column and found to be 2.46 at 5255A. A saturated solution of concentration c_2 contains at 23°C, 66.7 grams of permanganate per liter.[16] From this it may be calculated, assuming that the Beer-Lambert law holds approximately for saturated solutions that

$$\mu\kappa=c_2D\lambda/4\pi c_1\log_{10}e$$

(e is here the Naperian base.)

It follows that $\mu\kappa_{\max}=10^{-2}$ and as μ is of the order of unity i.e., about 1.3, the left-hand side of Eq. (1) is of numerical magnitude of about 5×10^{-3}. That is to say the term $jNe^2/3\pi\beta$ may be neglected in comparison with $(\mu^2-1)/(\mu^2+2)$ which is about 0.25.

In other words, at the point $\nu=\nu_\epsilon$ the whole contribution to the refractive index is the term b. If therefore a line be drawn to which the two ends of the dispersion curve are asymptotic, this will represent the variation of b. Where this line cuts the dispersion curve will be to a first order approximation the point $\nu=\nu_\epsilon$. This is found to be in the neighborhood of 5500A. As the absorption band nearest to this is at 5473A, this band may be considered to be that resulting from the fundamental electronic frequency, ν_ϵ.

Qualitatively this appears to be in agreement with observation. Formánek states that this band is the fundamental, arguing from the fact that this band alone persists at great dilution. As stated above it was thought probable from energy considerations that the first band at 5710A is $\nu_\epsilon-\nu_\tau$ and therefore the band at 5473A is the fundamental frequency ν_ϵ of an electronic transition in the manganese ion of the permanganate radicle.

[16] Seidell, *Solubility of Inorganic and Organic Compounds.*

Recent Advances in Sensitizers for the Photography of the Infrared*

L. G. S. Brooker, F. M. Hamer and C. E. K. Mees, *Kodak Research Laboratories*

(Received April 17, 1933)

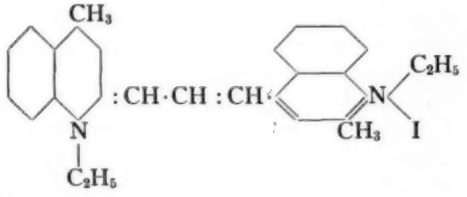
OVER fifty years ago Abney[1] photographed the infrared portion of the solar spectrum up to a wave-length of 9867A. This was done by the use of a special red-sensitive form of silver bromide emulsified in collodion. He described the emulsion as blue by transmitted light and as sensitive far into the infrared region; probably its sensitivity did not extend much beyond 10,000A, the image obtained beyond that point being due to scattered light. While certain observers have been able to reproduce Abney's results, others have failed to do so, so that his procedure cannot be regarded as of practical value.

Advancement has proceeded along other lines, —by the use of photographic sensitizers. Silver bromide itself is sensitive to only a narrow spectral region, comprising the ultraviolet, violet and blue. By treatment with photographic sensitizers, however, sensitivity to other parts of the spectrum is conferred. The sensitizer may either be incorporated in the emulsion or applied, by bathing, to the finished photographic material.

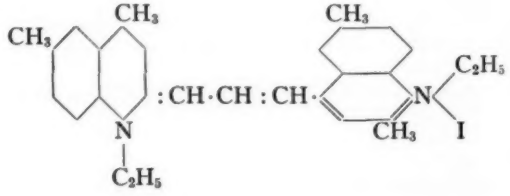
Higgs,[2] in his exhaustive study of the solar spectrum, sensitized an emulsion to red light by means of Alizarin Blue in the form of bisulfite compound, this being prepared by the treatment of Alizarin Blue base with sodium bisulfite solution.

Eder and Valenta[3] tested a great number of dyes and recommended certain of them for the photography of the red end of the solar spectrum. These included Diazo Black BHN, several of the Wool Blacks, and Columbia Green, with which the furthest extension into the red end of the solar spectrum was obtained by Valenta.

In 1906, Dicyanine was introduced by the Hoechst Dye Works, and a number of workers found that this dye would be valuable as a sensitizer for the infrared region.[4] With this dye, Merrill[5] and Meggers[6] photographed spectra as far as 9600A, not surpassing the point in the solar spectrum realized by Abney. Dicyanine was prepared by the condensation of 2 : 4-dimethylquinoline ethiodide, or 2 : 4 : 6-trimethylquinoline ethiodide, upon itself with simultaneous oxidation. Owing to the work of Mills and Odams,[7] its constitution is known to correspond to that of a 2 : 4′-carbocyanine, having the formula:



or



In 1919,[8] Adams and Haller, working at the Bureau of Chemistry, discovered a new dye which they termed *Kryptocyanine*. It was formed by the condensation of salts of lepidine in the presence of formaldehyde, and had a very strong sensitizing band between 7000 and 8000A, with its maximum near 7500A. This dye was shown by Mills and Braunholtz[9] to be the 4 : 4′-carbo-

* Communication No. 513 from the Kodak Research Laboratories.

[1] Abney, Phil. Trans. **171**, 653 (1880).

[2] Higgs, Proc. Roy. Soc. **A49**, 345 (1891).

[3] Eder and Valenta, *Beiträge zur Photochemie und Spectralanalyse*, Part 3, pp. 124, 166.

[4] Mees and Wratten, Phot. J. **32**, 25 (1908).

[5] Merrill, Bull. Bur. Stand. **14**, 487 (1918–1919).

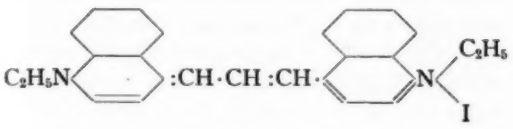
[6] Meggers, Bull. Bur. Stand. **14**, 371 (1918–1919).

[7] Mills and Odams, J. Chem. Soc. **125**, 1913 (1924).

[8] Adams and Haller, J. Am. Chem. Soc. **42**, 2661 (1920).

[9] Mills and Braunholtz, J. Chem. Soc. **123**, 2804 (1923).

cyanine, having the constitution

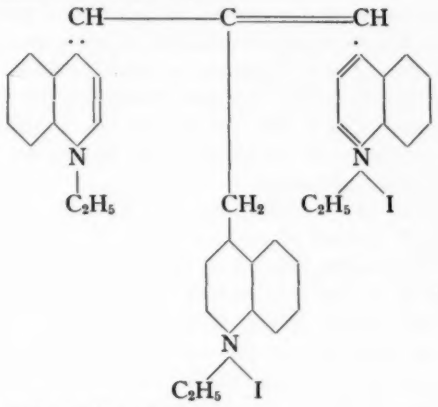


Kryptocyanine sensitizes quite differently from Dicyanine. It is stable and easy to use, and it can be added to the emulsion with excellent results, so that it is possible to produce ready-sensitized materials without difficulty. Only about one part in half a million of emulsion is required to give the maximum sensitization. In high concentrations, it produces fog.

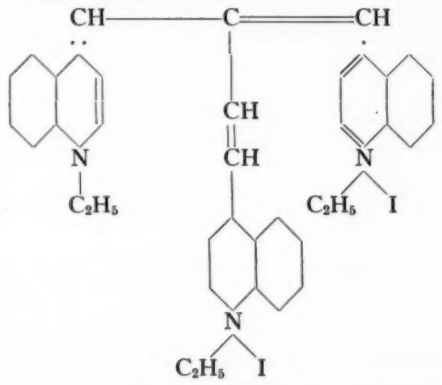
The introduction of Kryptocyanine opened up many possibilities. The photography of the spectrum as far as 8000A at once became easy, and throughout this range emission and absorption spectra could be measured without difficulty. Unfortunately, Kryptocyanine, while it sensitizes very powerfully up to 8000A, has very little sensitizing power beyond that, so that when we reach 9000A, its sensitizing power is considerably inferior to that of Dicyanine.

In 1925, H. T. Clarke,[10] while preparing Kryptocyanine, noticed that another dye of less solubility was formed during the reaction, and this was tested as a sensitizer by Dundon, Schoen and Briggs.[11] The new dye sensitized from 6500A to 9000A for moderate exposures, the maximum sensitivity being at 8200A. Hypersensitizing with ammonia made it very easy to extend the photography of the spectrum to well beyond 10,000A, and Babcock photographed the solar spectrum as far as 11,634A.[12] This dye, which was termed *Neocyanine*, has the satisfactory practical properties of Kryptocyanine, though it has much weaker sensitizing power and therefore requires long exposures.

The structure of Neocyanine was investigated by Hamer,[13] who has assigned the following formula to the ethiodide:



The alternative formula



appears the more probable from various considerations which it is hoped to present subsequently in more detail.

Up to the end of 1931, Neocyanine was the best sensitizer known for the photography of the extreme infrared, and with it the furthest extensions of the spectrum were photographed.

Recently, an entirely new group of dyes has become available as sensitizers for the infrared. In these dyes, known as tricarbocyanines, the two heterocyclic nuclei are linked by the seven-carbon chain, $:CH\cdot CH:CH\cdot CH:CH\cdot CH:CH\cdot$, whereas in the carbocyanines, such as Pinacyanol, Dicyanine and Kryptocyanine, for example, the linkage is through the three-carbon chain, $:CH\cdot CH:CH\cdot$, and in a group of dyes discovered by Beattie, Heilbron and Irving,[14]

[10] U. S. Patent 1,804,674 (1926).

[11] Dundon, Schoen and Briggs, J. Opt. Soc. Am. **12**, 397 (1926).

[12] Babcock, Smithsonian Institute Annual Reports, **1930**, 165.

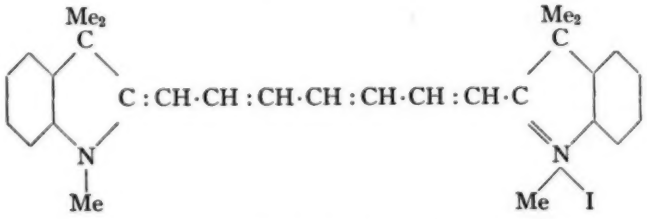
[13] Hamer, J. Chem. Soc. **1928**, 1472.

[14] Beattie, Heilbron and Irving, J. Chem. Soc. **1932**, 260. See also British Patent 353,889 (1930).

and named by them dicarbocyanines, the linkage is through a five-carbon chain. These particular dicarbocyanines, which contain a halogen atom or a nitro group as a substituent in the five-carbon chain, are sensitizers for the near infrared where the substituent is a halogen atom, but up to the present they have found no practical application.

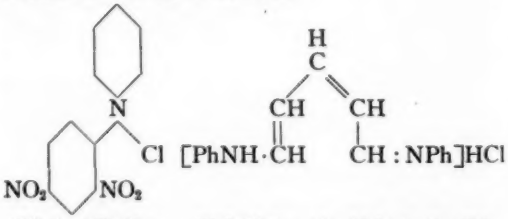
Now, the cyanine dyes in general possess sharply defined absorption bands. The positions of the maxima depend, in the first place, on the nature of the heterocyclic nuclei and, in the second, on the length of the polymethine chain which joins the nitrogen atoms. This latter component is, of course, affected by the positions of linking of the nuclei as well as by the length of the carbon chain joining them. It is well known that the cyanines, as a class, are photographic sensitizers, and that the position of the maximum of the band of extra sensitivity which any dye may confer on a photographic emulsion corresponds with that of the absorption maximum of the dye, being shifted somewhat towards the region of long wave-length. Since, of all cyanine dyes, the tricarbocyanines have the longest polymethine chains, it was expected that they would make it feasible to photograph further into the infrared than ever before. As is shown below, this expectation was fully realized.

It must first be recorded that the tricarbocyanines were discovered independently by three sets of workers. Wahl and the I. G. Farbenindustrie A.-G.[15] prepared the *indotricarbocyanine* (I) by condensing the appropriate quaternary salt (or the corresponding methylene base)



(I) 1 : 3 : 3 : 1′ : 3′ : 3′-Hexamethylindotricarbocyanine iodide.

with either of two compounds under certain conditions, while in other circumstances they produced an intermediate. I. C. I. Ltd., Piggott, and Rodd[16] prepared this same dye by a process related to, though not identical with, one of Wahl's, and they noted its photographic sensitizing properties. Meanwhile, this same field was being explored by one of us (F. M. H.) working in the laboratory of Ilford, Ltd., and two methods of synthesis were devised.[17] The two types of compound used for building up the polymethine chain which connects the nuclei were the same as those of Wahl, but the method of effecting the condensation differed from his; the generality of the methods was recognized in that they were applied to a variety of cyclic ammonium salts containing a reactive methyl group; moreover, the photographic properties of the dyes were thoroughly investigated. The chemical aspect of these two original methods is dealt with elsewhere,[18] and it can only be noted here that the first method consisted in the use of the compound II, while in the second method a compound such as III was used. In each case, condensation with a suitable quaternary salt, in alcoholic solution, was effected by means of the calculated amount of sodium dissolved in alcohol.



(II) 2 : 4-Dinitrophenylpyridinium chloride.

(III) Glutaconic aldehyde dianilide hydrochloride.

[15] German Patent 499,967 (1928).

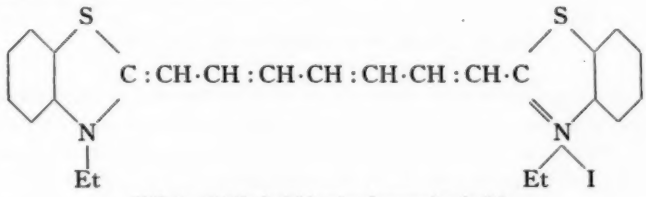
[16] British Patent 355,693 (1930).

[17] Hamer and Ilford Ltd., British Patent 351,555 (1930); 354,826 (1930).

[18] Fisher and Hamer, J. Chem. Soc. **1933**, 189.

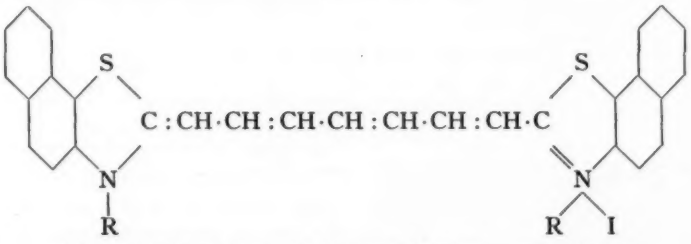
According to the first method, dinitraniline (1 : 2 : 4) is formed as a by-product, but according to the second, the only organic by-product is aniline hydrochloride, which is very readily removed; the second method is, therefore, greatly to be preferred to the first.

This method was at its best in the synthesis of the simple *thiatricarbocyanine* (IV), giving in this case a 41 percent yield of recrystallized dye. It was also applied to the preparation of the corresponding methyl compound and to that of two pairs of

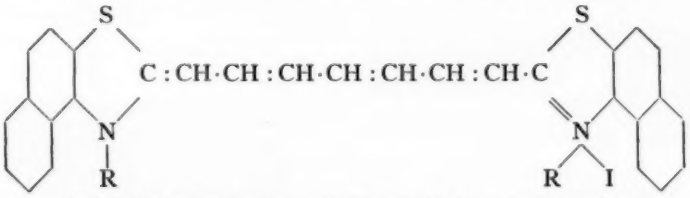


(IV) 2 : 2′-Diethylthiatricarbocyanine iodide.

dibenzothiatricarbocyanines (V and VI) derived from methyl-α- and β-naphthothiazolinium salts, respectively. The method also works well with quaternary salts of 1-methylbenzoselenazole, a base first used for cyanine dye formation by L. M. Clark,[19] or of 2-methylthiazoline, a base first applied to cyanine dye formation by one of us (L. G. S. B.).[20] In the former case, the products are

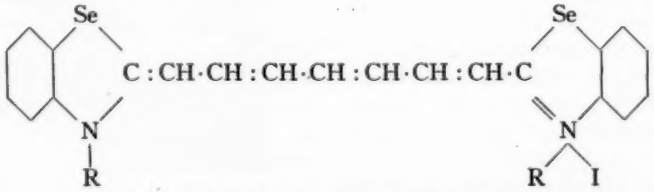


(V) 2 : 2′-Dialkyl-5 : 6 : 5′ : 6′-dibenzothiatricarbocyanine iodide.



(VI) 2 : 2′-Dialkyl-3 : 4 : 3′ : 4′-dibenzothiatricarbocyanine iodide.

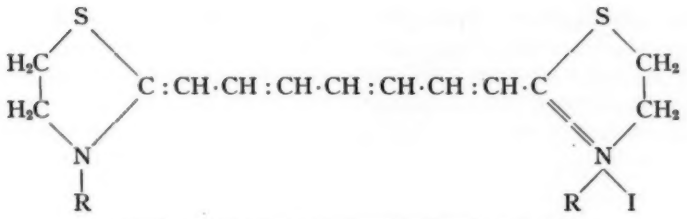
selenatricarbocyanines (VII) and, in the latter, *thiazolinotricarbocyanines* (VIII). Attempts to apply these two methods to



(VII) 2 : 2′-Dialkylselenatricarbocyanine iodide.

[19] Clark, J. Chem. Soc. **1928**, 2313.

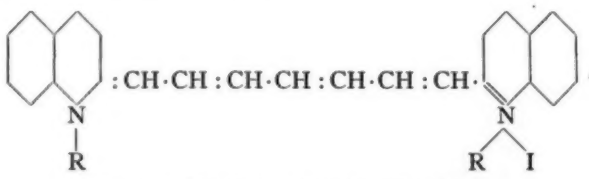
[20] Kodak-Pathé, French Patent 718,471 (1931).



(VIII) 3 : 3′-Dialkylthiazolinotricarbocyanine iodide.

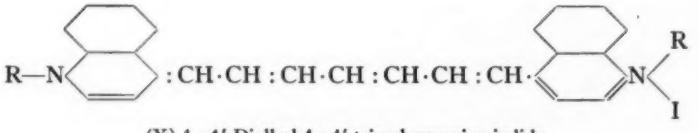
the preparation of oxatricarbocyanines proved fruitless. Nor was it possible to obtain I by either of the methods involving the use of sodium alcoholate, but this *indotricarbocyanine* was finally prepared by carrying out the condensation with III in the presence of acetic anhydride and sodium acetate, a process which differs somewhat from those described by the other workers in this field.

In the case of quinaldinium salts, difficulties in the preparation and purification of the dyes were encountered owing to their instability. Nevertheless, preparations of two *2 : 2′-tricarbocyanines* (IX), by both methods were carried through, the best yield of recrystallized dye being 13 per-cent.



(IX) 1 : 1′-Dialkyl-2 : 2′-tricarbocyanine iodide.

In the case of lepidinium salts, it was not found possible by these methods to isolate the *4 : 4′-tricarbocyanine*. In order to prepare this dye, it was found necessary by one of us (L. G. S. B.) to work at room temperature or somewhat lower and to effect the condensation by the use of piperidine. By this means the 4 : 4′-tricarbocyanine (X)

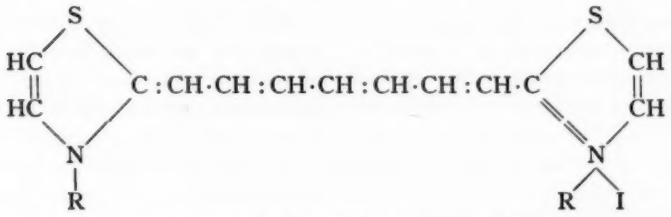


(X) 1 : 1′-Dialkyl-4 : 4′-tricarbocyanine iodide.

was isolated. In this compound, the two nitrogen atoms in the dye molecule are connected by a chain of no less than thirteen carbon atoms.

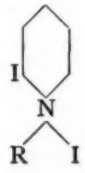
The dye itself, to which the name *Xenocyanine* was given, crystallizes from spirit in coppery crystals and gives dull green solutions which rapidly deteriorate on exposure to air. It has been found necessary to bring about solution of the dye, for incorporation in the emulsions, with little or no heating. In the solid state, when protected from air by being submerged in ether and when kept in a dark refrigerator, the crystals remain bright and apparently undecomposed for several months and give good results when tested photographically, but the best emulsions are those which have been made with freshly recrystallized dye.

It is worthy of notice that the *thiazolotricarbocyanines* (XI) are also readily obtainable by this method.

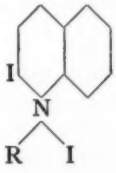


(XI) 3 : 3′-Dialkylthiazolotricarbocyanine iodide.

The tricarbocyanines may be prepared by another method. For instance, when a 1-methylbenzothiazole quaternary salt is treated with 2-iodopyridine alkyl iodide (XII) or 2-iodoquinoline alkyl iodide (XIII) in the presence of pyridine, a thiatricarbocyanine (IV) is produced in good yield.



(XII)



(XIII)

This method is very effective for the practical production of tricarbocyanine dyes.

The discovery of the tricarbocyanines has greatly facilitated and extended the photography of the infrared portion of the spectrum. In Fig. 1 are shown the spectra of a tungsten lamp taken through a diffraction grating with a black wedge in front of the slit upon plates sensitized with Dicyanine, Kryptocyanine and Neocyanine. It will be seen that the limit of sensitiveness with the last dye is approximately 9000A, extensions beyond this being obtained only by very long exposures.

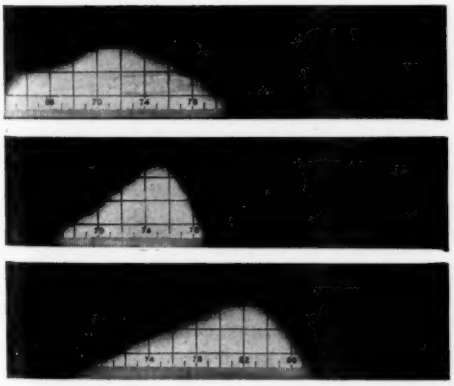


FIG. 1. Spectra obtained with Dicyanine, Kryptocyanine and Neocyanine. A, Dicyanine; B, Kryptocyanine; C, Neocyanine.

2 : 2′-Diethylthiatricarbocyanine iodide (IV) gives the sensitiveness shown in Fig. 2A. Its maximum is at 8100A, and its sensitizing power is considerably greater than that of Kryptocyanine, so that with this dye the spectral region from 7500A to 8500A is very easily photographed. Plates and films sensitized with this dye have been used for ordinary infrared photography, especially for objects at a great distance.

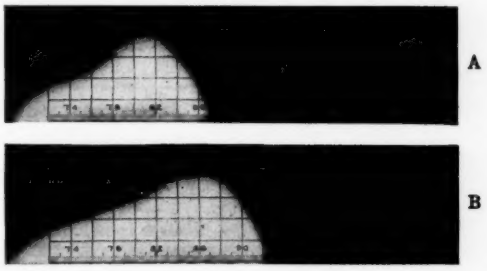


FIG. 2A. Spectrum photographed with thiatricarbocyanine. B. Spectrum photographed with dibenzothiatricarbocyanines.

The dibenzothiatricarbocyanines (V and VI) give the sensitizing effect shown in Fig. 2B, and with these dyes the spectral region from 8000A to 9000A becomes easily accessible to the spectroscopist. Plates sensitized with these dyes have also found some use for photography in the absence of visible light, since their high sensitiveness in the infrared makes it possible to take photographs of objects illuminated by low temperature sources or by light sources from which the visible radiation has been removed by means of filters.

The two sensitizers shown in this figure are of particular value for astronomical photography, since with large instruments even stellar spectra can be photographed in the infrared; and the region covered by 2B is particularly important because of the presence of strong calcium lines near the maximum sensitiveness of the dye.

The 4 : 4′-tricarbocyanine (X) prepared by the method described in this paper proved to be an excellent sensitizer. With this dye, the wedge spectrum shown in Fig. 3 was obtained, and with

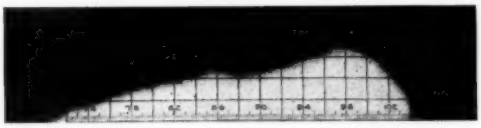


FIG. 3. Spectrum photographed with Xenocyanine.

it the furthest extensions into the infrared regions of the spectrum have been made—notably, by Meggers and Kiess.[21] By means of it, the spectral region from 9000A to 11,000A becomes easily accessible. The strong mercury line at 10,140A can be photographed with very short exposures, and such lines as the resonance lines of helium at 10,830A can be photographed without difficulty.

All of these dyes are somewhat difficult to use in practice, and much better results are obtained by incorporating them in the emulsion than by any bathing process, the technique in the case of Xenocyanine being particularly difficult.

The thiazolinotricarbocyanine (VIII) gives strong sensitizing with a maximum at 7100A, and since it is rather difficult to sensitize for this region of the spectrum, the dye is of great value (Fig. 4).

FIG. 4. Spectrum photographed with thiazolinotricarbocyanine.

In concluding this paper, it may be well to illustrate the progress which has been made in increasing the spectral region for which photography can be employed in practice, and for this purpose the diagram shown in Fig. 5 is inserted. This is, of course, purely diagrammatic, but the extensions shown are approximately comparable. The extension shown up to 1919 as compared with

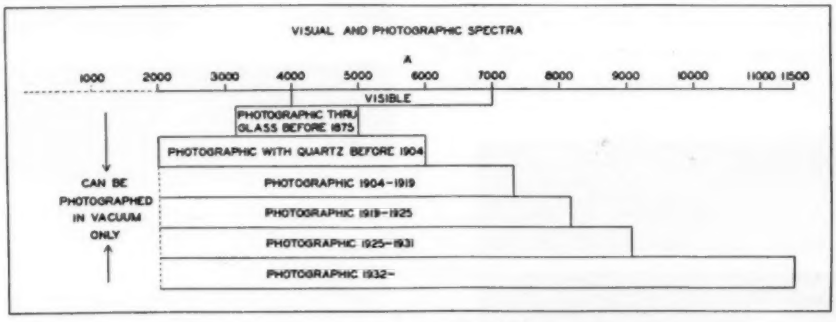


FIG. 5. Diagram showing extension of the spectrum.

1904 is due to the introduction of Pinacyanol, the use of Dicyanine for the infrared being ignored since that use was very limited. The extension in 1919 was due to the introduction of Kryptocyanine; that of 1925, to the introduction of Neocyanine; and that of 1932, to the introduction of Xenocyanine. In addition to the extension of the spectrum, the regions already known have, of course, been made much more easily accessible with shorter exposures by the synthesis of the dyes described in this paper.

[21] Meggers and Kiess, Bur. Standards J. Research 9, 309 (1932).

Journal of the Optical Society of America

The Review of Scientific Instruments

Statement of Cash Receipts and Disbursements

For the Period from January 1, 1932 to December 31, 1932

Cash on Hand, January 1, 1932		$ 257.03
Receipts:		
In account with the Optical Society of America (12 issues at $400.00 each)		4,800.00*
In account with Scientific Apparatus Makers of America Advertising		6,040.50
Miscellaneous receipts:		
Subscriptions	$ 2,339.11	
Sale of back numbers	325.21	
Reimbursement	6.00	
Transfer from interest account	4,800.00	7,470.32
Total		$18,567.85
Disbursements:		
Printer	$12,538.50	
Salaries and office expenses	5,397.48	
Miscellaneous	524.35	$18,460.33
Cash on hand, December 31, 1932		107.52
Total		$18,567.85

* Includes $400 in payment for December, received January, 1933.

The above is a correct statement of accounts to the best of my knowledge and belief.

(*Signed*) F. K. Richtmyer, *Business Manager*

We, the undersigned, duly appointed to audit the accounts of the Journal of the Optical Society of America and The Review of Scientific Instruments at the close of business, December 31, 1932, hereby certify that we have examined the statement of receipts, and disbursements, the vouchers, check book and bank book and find them to agree with each other. We, therefore, certify that the above statement is a true statement of the accounts of the Journal of the Optical Society of America and The Review of Scientific Instruments as of December 31, 1932.

(*Signed*) G. E. Grantham
F. R. Hirsh, Jr.

Annual Report of the Secretary of the Optical Society of America for the Calendar Year 1932

Membership Record

January 1, 1932 to January 1, 1933

	Honorary	*Regular Annual Payment*	*Regular Life Payment*	*Associate Individual Annual Payment*	*Associate Corporation*	*Total*
Membership as of record in the books of the Secretary and Treasurer 1-1-32	4[1]	420	8	249	13	694[1]
Counted twice[1]						1–
Net						693
Gain in 1931 (not previously reported)[2]						1+
Membership as of 1-1-32	4	420	8	249	13	694
Gains during 1932						
By election during 1932 as of 1-1-32	0	0	0	21	0	21+
Losses during 1932						
By death	1	5	2	0	0	8–
By resignation as of 1-1-32	0	6	0	6	2	14–
By dissolution of Optical Society of London	1[3]					1–
Membership as of record 12-31-32	2	409	6	264	11	692
Gains between 12-31-32 and 1-1-33						
By election during 1932 as of 1-1-33	0	0	0	5	0	5+
By transfer 10-14-32 as of 1-1-33	0	13	0	0	0	13+
Losses between 12-31-32 and 1-1-33						
By transfer 10-14-32 as of 1-1-33	0	0	0	13	0	13–
By resignation during 1932 as of 12-31-32	0	10	0	14	1	25–
Membership as of record 1-1-33	2	412	6	242	10	672

[1] Frank Twyman, past President of the Optical Society of London, is a regular member and was ex-officio honorary member during his term of office.

[2] Frank Twyman was replaced as honorary member on May 14, 1931, by A. O. Rankine, the newly elected President of the Optical Society of London.

[3] The Optical Society of London was dissolved September 22, 1932, terminating the ex-officio honorary membership of A. O. Rankine.

Elected during 1932 as of January 1, 1932

Hollis S. Baird (929 A)
Clinton L. Brooke (923 A)
Walter Clark (913 R)
Ralph W. Duncan (915 A)
M. H. Eisenhart (910 R)
N. A. Esserman (925 A)
Charles K. Hayden (909 A)
Kurt J. Heinecke (916 A)
William Herriott (926 R)
F. M. Emerson Holmes (911 A)
Overton Luhr (921 A)
Eugene F. McCarthy (928 A)
John W. McFarlane (912 R)
Julian Ellis Mack (924 R)
Philip Runals Mayo (917 A)
Wayne B. Nottingham (922 R)
H. M. O'Bryan (927 R)
Marion Edward Russell (918 R)
Francis W. Sears (919 A)
John Joseph Such (920 A)
James S. Thompson (914 A)

Elected during 1932 as of January 1, 1933

Clarence H. Graham (932 R)
Arthur W. Kenney (934 A)
David L. MacAdam (930 A)
Harry William Mountcastle (931 R)
Sidney M. Newhall (933 A)

Elected to Regular Membership by Action of the Council October 14, 1932, Effective January 1, 1933

Walter Clark (913 R)
John I. Crabtree (908 R)
M. H. Eisenhart (910 R)
Paul R. Gleason (903 R)
Clarence H. Graham (932 R)
William Herriott (926 R)
John W. McFarlane (912 R)
Julian Ellis Mack (924 R)
Harry William Mountcastle (931 R)
Wayne B. Nottingham (922 R)
H. M. O'Bryan (927 R)
Otto Oldenberg (904 R)
Marion Edward Russell (918 R)

Deaths during 1932

Nathan H. Brachma (649 R)
George K. Burgess (343 R)
George Eastman (128 RL)
Charles S. Hastings (61 H)
George F. Kunz (278 R)
Adolph Lomb (15 RL)
Irwin G. Priest (22 R)
Leonard T. Troland (31 R)

Resignations during 1932 as of January 1, 1932

Robert Victor Baud (703 R)
Central Scientific Company (627 AC)
Cooper Hewitt Electric Company (629 AC)
H. Franklin Dawes (272 R)
Howard C. Doane (457 A)
Elmer H. Finch (678 A)
Harvey James Howard (556 R)
Franklin L. Hunt (341 R)
Thomas J. Killian (689 A)
Henry L. Logan (437 A)
Henry F. Raess (542 A)
Irwin Roman (544 R)
Toshio Takamine (816 A)
W. D. Wright (714 R)

Resignations during 1932 as of December 31, 1932

John P. Arnold (575 A)
William L. Benedict (325 R)
Charles C. Bidwell (256 R)
F. C. Blake (314 R)
Walter L. Cheney (733 A)
Martin Cohen (234 R)
Casper L. Cottrell (323 A)
John C. Duncan (578 R)
Hugo Fricke (253 R)
E. L. Harrington (768 A)
Cedric Edward Hesthal (651 A)
L. R. Ingersoll (136 R)
Vladimir Karapetoff (716 A)
Dean A. Lyon (552 A)
Paul McCorkle (729 A)
Louis Williams McKeehan (334 R)
D. W. Morehouse (796 R)
Alexander McLean Nicolson (832 A)
Dorus P. Randall (826 A)
William Schriever (772 A)
Forrest Clifford Shaffer (898 A)
Francis B. Silsbee (754 A)
Roy C. Spencer (815 A)
Spencer Lens Company (715 AC)
Harold Albert Wilson (540 R)

(*Signed*) L. B. TUCKERMAN,
Secretary.

Optical Society of America

Statement of Cash Receipts and Disbursements

For the Period from January 1, 1932 to December 31, 1932

Cash on Hand, January 1, 1932		$ 6,120.75
Receipts:		
Membership dues arrears, 1931	$ 42.50	
Membership dues current, 1932	3,721.21	
Subscription to support of society	1,500.00	
Interest on bank balances	157.62	
Interest on bonds	832.50	
Interest on bonds (Ives Fund—500 Lib.)	21.25	
Share of society in journal subscriptions	62.10	
Share of society from advertisements in journal	200.00	
Sales of back numbers Vols. I–V	47.54	
Total Receipts		6,584.72
Total Receipts Plus Cash on Hand, January 1, 1932		$12,705.47
Disbursements:		
To Journal of the Optical Society of America and The Review of Scientific Instruments as per contract with Association of Scientific Apparatus Makers of U. S. (11 Months at $400.00)	$4,400.00	
Printing and Stationery	225.11	
Postage and telegrams	67.19	
Postage—back numbers of journal	1.10	
Travelling	135.90	
Clerical expense	141.25	
Fire insurance, Vols. I–V	6.80	
Labor and transportation on addressograph	72.72	
Dues, Inter-Society Color Council	25.00	
Sundry expense	33.10	
Total disbursements		$ 5,108.17
Cash on hand December 31, 1932		7,597.30
Total Disbursements Plus Cash on Hand December 31, 1932		$12,705.47

Investments:

$7,000 Atchison, Topeka & Santa Fe Gen. 4's
13,000 Fourth Liberty 4¼'s
500 Fourth Liberty 4¼'s (Frederick Ives Medal Endowment Fund)

I certify that the above report is correct to the best of my knowledge and belief.

. (*Signed*) HENRY F. KURTZ, *Treasurer*

February 15, 1933

The undersigned, having been duly appointed to audit the books of the Treasurer of the Optical Society of America from October 20 to December 31, 1932, hereby certify that the Treasurer's official report of receipts, disbursements, investments and assets is correct in every detail, as shown by bank statements, vouchers, etc.

(*Signed*) CARL L. BAUSCH
C. W. FREDERICK